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Comparison of Different Cemented Tungsten Carbides Applied to Particleboard Machining End Mills

F. Jorge Lino^{1,2}, João Guimarães¹, Luís Teixeira², A. Monteiro Baptista², Tiago Fernandes³, Fernando Figueiredo³*

¹*INEGI – Instituto de Engenharia Mecânica e Gestão Industrial, Porto, Portugal*

²*Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Mecânica e Gestão Industrial, Porto, Portugal*

³*Frezite, Trofa, Portugal *Email: falves@fe.up.pt*

Abstract

Nowadays, many industrial companies have already established procedures to incorporate recycled products in their production lines. According to recent statistics, the wood recycling is growing exponentially, with products like MDF (medium density fiberboard), OSB (oriented strand board) or Particleboards being more and more important in the wood/furniture industry. Many times these products have different types of debris (small stones, metallic nails, etc.) that escape from the controller in the manufacturing lines. Machining these particleboards is very challenging, especially because of the wear defects that the debris can cause to the tool cutting edges. This study focus a comparative analysis of three grades of tungsten carbide “up down” (two cutting edges that compress the board edges) end mills applied to particleboard machining. The role of the grain size, binder content and carbides hardness is presented and how it affects the wear resistance and tools life.

Keywords: Tungsten carbide, grain size, binder content, wear, machining, particleboards.

1. Introduction

Actually, the wood industry has special concern with environmental issues, preferring the use of recycled wood materials instead of the typical forest resource. The wood, assumed as the only 100% renewable, recyclable, reusable and biodegradable resource [1], is used in a wide spectrum of applications, from the simple cooking spoon to the building construction. The use of recycled wood is not just a simple fact of environmental concern, but also a way of controlling this resource, and mainly to take profit of its characteristics. There are a lot of recycled wood products, with the most varied applications. The variety of these materials provides important products such as wood panels, in which the MDF, the OSB or the Particleboard are assumed as some of the most employed. These materials have a lot of applications, mainly in the construction and furniture branch. Besides of being suitable for all general uses in furniture or construction, the particleboard can be used in dry or occasionally wet conditions, or even for fire retardant applications. It can be employed in raw condition or surfaced with wood veneers, melamine decorative papers or even thin foils [2]. Manufactured in a very wide range of sizes and thicknesses, the particleboards can also be used for band-aid solutions (while building procedures), for flooring and doors.

The particleboard panels are usually manufactured with composition of wood particles varying between 83 and 88%, 6 to 8% of resin, 5 to 7% of water, and 1 to 2% of paraffin, mixed with urea-formaldehyde resin [3]. The usual particleboard production goes through a sorting process of the recycled particles, where the useful and undesired particles are separated. During this process, and due to its industrial difficulty, it is common to find some unwanted debris such as small stones, metallic nails, etc; that escape from the process devices and controllers, giving rise to negative consequences, namely accelerated degradation of the machining tools.

For the machining processes of the particleboards, the most used tool materials are the cemented carbides, which introduction brought a significant improvement to the tools life [4]. The different grades and chemical composition, allied to the use of synthetic diamond inserts, provide a very wide role of tools applications.

The machining operations are divided in different processes, such as sawing, drilling or milling (process used in this study). Generally, the end mills geometry vary on the number of flutes, and on the chip removing directions: *Up-cut spiral*, *Down-cut spiral* and *Up-Down-cut spirals*. As more flutes are used, higher speed applications are allowed, providing faster chip removal and higher machining quality. The *Up-cut spiral* end mill produces a chip removal in the ascendant direction, providing a good finish to the lower surface of the machined panel. The *up* force that the end mill transmits to the board causes a special concern for the board fastening. The *Down-cut spiral* end mill allows higher feed rates for the same conditions, due to the down force caused by the *down* motion of the mill, helping the fixation of the board. This kind of geometry provides the best finishing to the upper surface, besides the difficulty of the chip removal.

The *Up-Down-cut spiral* end mills are mostly used to machine boards where the perfect finishing of the two edges is desired. This tool geometry avoids the disintegration of the particleboard boundaries, due to the forces caused by the cutting edges: the forces are carried out from the periphery to the core of the board. The disadvantage of this use, when compared with other geometries, is the limited feed rate considering the chip removal difficulty.

The wear behavior in machining wood based products is substantially different of what is verified in the working of solid wood. Mainly, the wear is caused by binder removal, which affects the consistence of the matrix, allowing the mechanical removal of carbide grains, provoking catastrophic damages to the cutting edges of the tool [5]. The tool wear mechanisms present in the machining of wood based products may be considered as gross fracture or chipping, abrasion, erosion, microfracture, chemical and electrochemical corrosion and oxidation. The gross fracture results in the failure of the tool in the early stages of the cut, while the other mechanisms act progressively. The abrasion, erosion and microfracture involve the mechanical removal of microscopic wear particles. Corrosion and oxidation involve the chemical transformation of the tool material into softer or more brittle compounds which can be easily removed from the cutting edge by abrasion [6].

In the early and most critical stage of the cutting process, the binder phase is partial removed from the grain interstices by plastic deformation and microabrasion. Many times the silica particles present in the particleboard act in the cut interface and promote the binder removal by microabrasion. This binder elimination allows the mechanical taking away of the carbide grains. The grains positional oscillation in the WC matrix, resulting from the oscillation forces produced during machining particleboards due the heterogeneous nature of its structure, will partially extrude the binder. In that point, the binder is removed by plastic deformation and microabrasion [5, 7].

Usually, the combination of the grain size and binder content regulate the phenomena [8], but certain debris such as small stones or metallic nails can shorten the tool life. The other mechanisms can depend on the material to machine and also on the atmosphere where the operations are performed.

This research was done in cooperation with two companies (a tool manufacturer and a tool user for particleboard machining) with the aim of making the connection between the research and development performed at university and industry. It is expected that important data for particleboards machining tool manufacturers is acquired.

2. Materials and Experimental Details

The tool materials used in this research include three different grades of cobalt-tungsten carbide (WC-Co). The grain size and the consequent hardness were also studied for the prediction of the tool life tests. Micro-abrasive wear tests were carried out using different specimens of the respective grades, with the intention of predicting the tool life. The surface quality of the tool cutting edges, surfaces and flutes were meticulously measured

through roughness measurements. The tools were also submitted to visual inspection with macrograph registrations.

The experimental sessions were defined based on previous experimental knowledge and were divided in different steps. Each step was designed to characterize the tool cutting edge evolution – wear tendency. After each step, macrographs were registered and roughness measurements were carried out.

2.1. Tools

The tools used in this study are two flute end mills, with *Up-Down-cut* spiral geometry, as shown in Fig. 1.

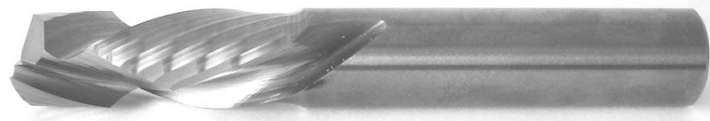


Fig. 1 - Up-Down-cut spiral end mill.

The three WC-Co grades, having different chemical composition, grain size and hardness, are indicated in Table 1.

	% C	% W	% Co	Average grain area (μm^2)	Hardness (HV 200)
Material A	4,37	93,69	1,94	0,38	1816
Material B	3,80	88,14	8,06	0,19	1611
Material C	5,37	85,91	8,73	0,32	1636

Table 1. Chemical composition, average grain area and hardness of the three studied materials.

The laboratory materials characterization was performed with the support of the following instruments: Scanning Electron Microscope, with proper image analysis software for counting and measuring the grains of each sample, used for chemical characterization and grain size calculation; *SHIMADZU HMV 2000*, with a load of 200 g applied for 10 to 15 seconds in each trial, for hardness measurements.

The microstructure is different in the three specimens, as shown in Fig. 2, where it is visible the lower grain size of Material B and the smaller binder content of Material A.

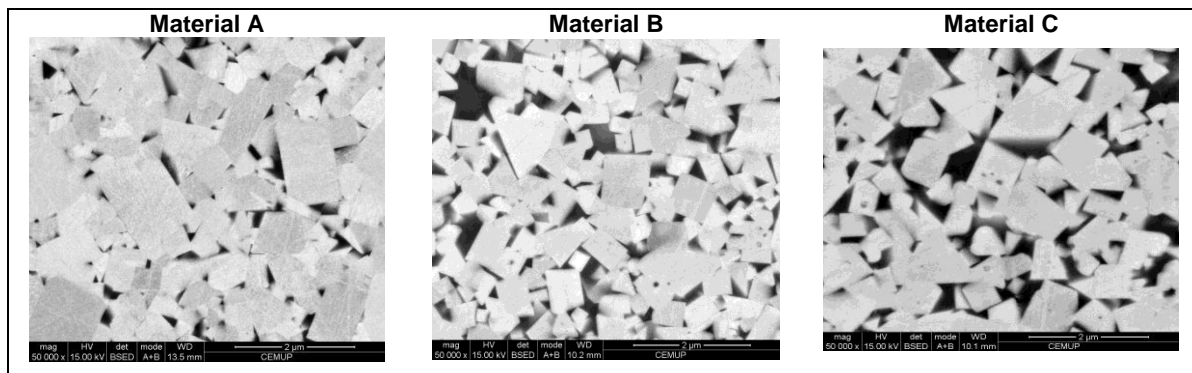


Fig. 2 - Microstructures of the studied materials.

The tribological tests were carried out on a *PLINT TE 66 Micro-Scale Abrasion Tester*, and were performed by the continuous contact of a steel sphere (diameter 25 mm) in the presence of an aqueous abrasive slurry of *Silicon Carbide Powder (1200 GRIT, 100ml H₂O for 20 g SiC)*. These tests were divided in 5 steps, corresponding to 100, 200, 300, 500 and 700 rotations for each run at 80 rpm under a load of 0,25 N [9].

The results, presented in Fig. 3, revealed a distinguished performance for Material A, which is expected to present the best behavior in industrial tests. The worn volume of this sample, after 700 revolutions, is similar to the second best, after only 300 revolutions.

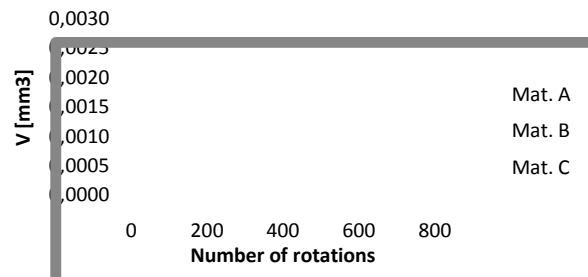


Fig. 3 - Micro-abrasive tribological performance comparison - worn volume (V) versus number of sphere revolutions.

2.2. Particleboard

The machining process involved doors manufacturing in an industrial environment. The panel composition is mainly a particleboard with other plate attachments to ensure specific characteristics to the door application. The constitution of the boards to machine, as shown in the Fig. 4, is a 28 mm thickness particleboard together with two thinner plates of MDF, 3 mm each, with a veneer finish, varying its specific weight between 540 and 560 kg/m³ for all the tests. This small variation is consequence of working directly with the industry where sometimes certain variables are not restrainable.

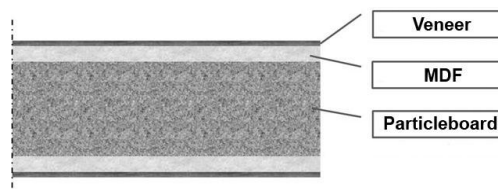


Fig. 4 - Schema of the door board constitution.

3. Experimental Process

This machining operation is one of the last phases of the door production process and requires high levels of quality. The referred operation consists on full depth milling, in order to allow forward glazing, with glass, wood, or other kind of material.

The operations plan consisted in two groups of three tools, with one tool of each material per group. The plan for the first group was divided in 5 steps (see Table 2) with the aim of understanding the behavior of the tools along its life. The second group plan was only divided in 3 steps, with the intention of confirming the convergence of the previous obtained results. Before the first and after each experience step, the tool surfaces were analyzed for macrograph registrations and roughness measurements.

The board machining was full depth performed with a constant spindle speed of 18.000 rpm in all the experiences. Varying the feed rate, allowed to understand the typical industry use and to acquire important data as the maximum values for certain spindle speeds. These numbers varied between 11 and 30 m/min, as shown in Table 2.

Group 1				
	Feed Rate (m/min)	Cutting Length (m)		
		Material A	Material B	Material C
Step 1	14,0	79.800	79.800	79.800
Step 2	14,0	83.820	83.820	83.820
Step 3	11,0	40.000	40.000	40.000
Step 4	13,0	70.460	70.460	70.460
Step 5	11,0	412.128	0	0
	Total	686.208	274.080	274.080

Group 2				
	Feed Rate (m/min)	Cutting Length (m)		
		Material A	Material B	Material C
Step 1	30,0	115.768	141.500	107.108
Step 2	30,0	148.960	122.360	154.280
Step 3	15,0	317.186	95.085	73.474
	Total	581.914	358.945	334.862

Table 2 – Operations plan for two tool groups.

4. Discussion of Results

The considered results are given by the performance of each tool (cutting length), roughness measurements and macrograph registrations. Table 3 shows the cutting length performance of each end mill and the average for each material. It is visible that the

performance of Material A exceeds the other materials in almost the double of the cutting length.

	Cutting Length (m)		
	Material A	Material B	Material C
Group 1	686.208	274.080	274.080
Group 2	581.914	358.945	334.862
Average	634.061	316.513	304.471

Table 3 – Average cutting length performance of the tested materials.

The roughness measured along each step was registered with the parameters R_a , R_z and R_{max} for all the flutes and some surfaces.

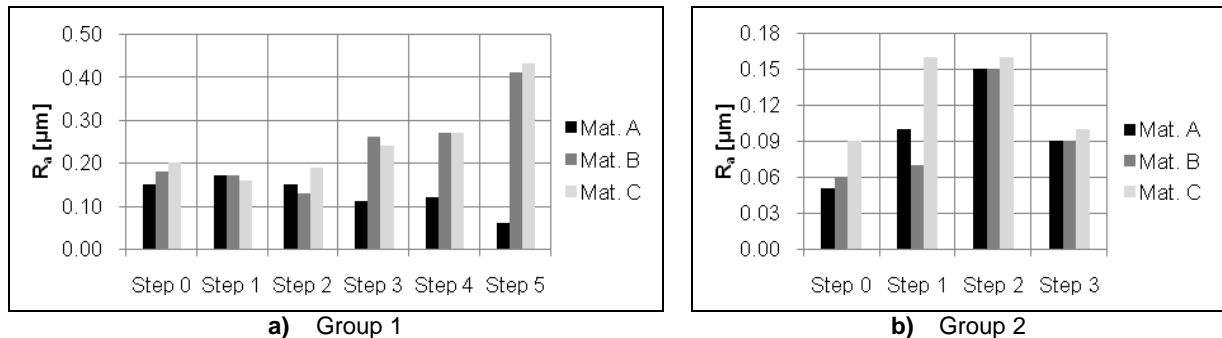


Fig. 5 – R_a – Arithmetic Average Roughness on the: a) Up surface flute; b) Down surface flute.

Fig. 5 a) shows a growing R_a evolution for the materials B and C due to its wear, but at the same time, the Material A evolves in opposite direction, denoting a polishing process. Fig. 5 b) has some similarities with a), and two aspects are relevant: the step 3 shows an equivalent surface state of the 3 materials, and also a decreasing from the previous step; the Material A shows an ascending roughness evolution along the steps, as opposite to the results shown in a). There were some peaks on the registered measurements, caused by measuring in places where would have occurred some defects such as a grain removals or scratches provoked by hard debris present in the boards.

The visual inspection was very important due to its clear information and comparison along the tests. Fig. 6 shows the evolution of the *Up-cut* edge of the Material A end mill. It is visible the exaggerated wear after the step 5.

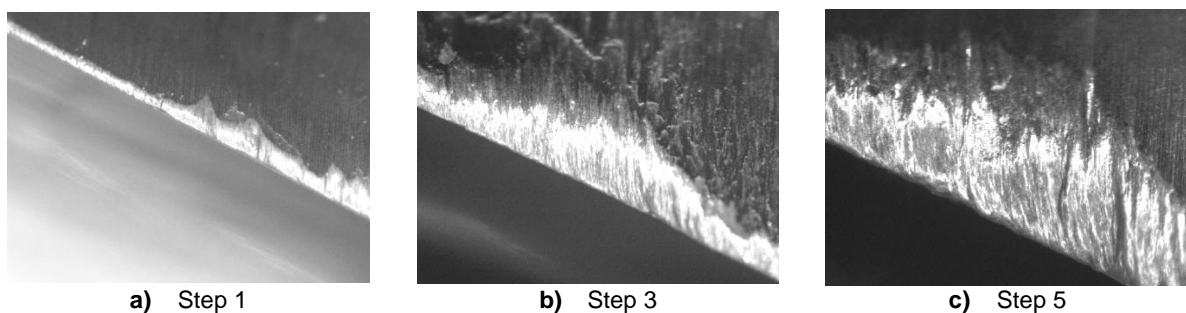


Fig. 6 - Macrographs registration of the evolution of the edge UP of the Material A - Group 1.

The defects, either on the tools or on the machined boards, were studied to clarify the causes of such incidents. Some metallic nails were detected, but no silica debris (small stones) were detected. These particles can cause serious damages to the tool, such as breaking the cutting edge. As the steps were being performed, the machining defects on the boards started to appear. The most visible one was the existence of splinters on the edges of the machined surfaces – indicating the reaching of the end of tool's life. This defect is caused by the intensive wear of the tool, and starts to happen when the tool becomes blunt and is not able to perform a clean cut. According to the machine operator's experience, it was visible that sometimes, before this phenomena occurrence, there was another defect identified by the human touch: the particleboard showed some kind of belly, instead of being

straight faced with the MDF machined boards. The tool edges start to be blunt and compress the material instead of cutting it. As the MDF has higher density than the particleboard, it remained in the desired machined geometry, but the particleboard, due to its lower specific weight, was compressed and then expanded, exceeding the wanted machining dimensions.

The overheating was identified in one experience which left marks on both, tools and boards. The boards used in this trial were constituted by higher density particleboard and by thicker MDF plates, conferring a higher specific weight to the final material to machine. Although the marks on the materials B and C were very visible, the Material A tool had no marks at all. The main explanation for this occurrence is the difference of the materials thermal conductivity. This property, in the WC-Co, is mainly controlled by the binder content (Co): as more binder, less thermal conductivity. The Material A, as shown in Table 1, had less than 2% of binder in its chemical composition, and the other two had more than 8%, meaning, by inter and extrapolation of other known data [10], that the approximate thermal conductivity rates for the materials A, B and C were roughly 126, 90 and 82 W/m.K. According to this data, the difference was enough, for the considered conditions, to reduce the overheating of either board or Material A tool due to its heat drainage promptness.

5. Conclusions

This study allowed a better understanding of the relations among some variables in order to understand the performance of the chosen materials for the tool construction.

The grain size is related with the binder content and the hardness and allows accomplishing that the most contributor factor for the levels of hardness is the binder content.

The micro-abrasion wear tests allowed predicting the tool wear and performance, proving in this case that as harder is the material (for the range presented), higher is the performance.

The roughness measurements were important to understand the surface degradation process, although some defects were not conclusive due to its high variations caused by untypical presence of scratches, grain removal or gross fracture. Anyway, the lowest amplitude was presented by the Material A. The macrograph registrations were important due to the detailed image analysis which allowed the monitorization of the wear evolution and the main tool defects. Despite the frequent detection of gross fracture and grain removal on the cutting edges, the Material A showed the best wear resistance. This phenomenon was caused by the larger grain size and the low binder content.

This research proved the initial prediction confirmed by the excellent performance of the Material A when compared to the other tested materials under the same conditions.

With all the acquired information, it is predictable that for the same conditions, the use of a material with low binder (Cobalt) content and smaller grain size, the mechanical removal of the grains would be less probable, due to the expected forces acting on the grains after the binder removal. If the grains would be smaller, the tool would be less vulnerable to the grain removal process.

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